DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

REPORT 447

ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

64 RUE DE VARENNE, PARIS VII

REPORT 447

NASA VARIABLE-GEOMETRY RESEARCH

by

T. A. TOLL, E. C. POLHAMUS and W. S. AIKEN, Jr.

APRIL 1963

NORTH ATLANTIC TREATY ORGANIZATION

NORWAY NORVEGE	Mr. O. Blichner Norwegian Defence Research Establishment Kjeller per Lilleström
PORTUGAL	Col. J.A. de Almeida Viama (Delegado Nacional do 'AGARD') Direcção do Serviço de Material da F.A. Rua da Escola Politecnica, 42 Lisboa
TURKEY TURQUIE	Ministry of National Defence Ankara Attn. AGARD National Delegate
UNITED KINGDOM ROYAUME UNI	Ministry of Aviation T.I.L., Room 009A First Avenue House High Holborn London W.C.1
UNITED STATES ETATS UNIS	National Aeronautics and Space Administration (NASA) 1520 H Street, N.W. Washington 25, D.C.

Printed by Technical Editing and Reproduction Ltd
Harford House, 7-9 Charlotte St. London. W.1.

REPORT 447

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

NASA VARIABLE-GEOMETRY RESEARCH

by

T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.

This Report was presented at the Twenty-Second Meeting of the Flight Mechanics Panel,
held in Torino, Italy, 16-19 April 1963

SUMMARY

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

SOMMAIRE

On esquisse les activités de recherche passées, présentes et futures probables de NASA relativement aux applications de la géométrie variable. On donne l'exposé général des raisons en faveur de considérer la géométrie variable. On résume les progrès passés pour montrer comment ils ont abouti à la souplesse opérationnelle accrue des appareils. On souligne le programme de flèche variable. Une brève description est donnée des aspects historiques et des objectifs de ces activités. On décrit aussi les diverses voies d'approche déjà explorées, ainsi que certains de leurs avantages. On esquisse l'ampleur du programme NASA relativement aux configurations, aux études de missions, aux structures, aux mécanismes, aux vibrations des bords de fuite et aux problèmes de pilotage. Pour conclure, ce rapport exprime de brèves idées sur les applications futures possibles de la géométrie variable aux programmes tant aéronautiques que spatiaux.

629.135:533.693.49

3c5

CONTENTS

LIST OF FIGURES

NASA VARIABLE-GEOMETRY RESEARCH

Thomas A. Toll*, Edward C. Polhamus**, William S. Aiken, Jr.***

DISCUSSION

Variable geometry in aircraft design has received so much attention recently that some may regard it as a new concept. This is far from true; in fact, a little reflection on events of the past will show clearly that advances in aeronautics have been closely linked to the introduction of many different variable-geometry features. The following tabulation is only a partial list of significant variable-geometry items, ranging in approximately chronological order from the wing flaps, which were devised at a very early date to provide attitude control, to the popular item of today - variable wing sweep.

Flaps (control and lift)
Retractable landing gear
Wing leading-edge slots and flaps
Variable-pitch propellers
Jettisonable fuel tanks
Engine cowl-air flaps
Drag brakes
Swivelling propellers, engines, and nozzles for VTO
Variable exhaust nozzles
Variable wing incidence
Folding fins
Folding wing tips
Retractable windshield fairing
Variable inlets
Variable wing sweep.

The expression 'multi-mission capability' has also received considerable stress in recent years. Again, this is not a recent innovation. In fact, the aircraft of 20 to 30 years ago, though limited in performance, were used for a greater variety of missions than are most of our modern aircraft. The use of variable-geometry features certainly added to the mission capabilities of the early aircraft. Consider, for

---

* *Chief, Research Division, NASA Flight Research Center, Edwards, California, U.S.A.*
** *Assistant Head, 7ft x 10ft Wind Tunnels Branch, NASA Langley Research Center, Langley Station, Hampton, Virginia, U.S.A.*
*** *Chief, Operations Research, Office of Aeronautical Research, NASA Headquarters, Washington, D.C., U.S.A.*

example, the retractable landing gear used in conjunction with a flying-boat hull to permit amphibious operations, or the jettisonable fuel tanks which provided our World War II fighters with a very respectable ferry range.

The breadth of mission capability narrowed appreciably as we progressed into the transonic and supersonic speed ranges. We tended to accept, essentially, a single-mission capability, because our demand for the maximum possible speed was of overriding importance and could be compromised only to the extent necessary to provide the minimum acceptable performance for off-design conditions. Nevertheless, new variable-geometry features continued to be introduced, if for no other reason than to allow the airplane to function satisfactorily over a wide Mach number range. In this category are variable wing incidence and folding fins, as used on the Mach 2 Navy F8U fighter, and the folding wing tips, retractable windshield fairing, and variable inlets of the Mach 3 North American Aviation B-70. Attempts to provide genuine multi-mission capability in high-performance aircraft, however, have been taken seriously only within the last few years.

The following factors are considered to be pertinent in establishing the feasibility of new aircraft:

(a) State of the art

$$\left.\begin{array}{l}\text{Aerodynamics}\\ \text{Propulsion}\\ \text{Structures}\\ \text{Operations}\end{array}\right\}\ \text{Design ingenuity}$$

(b) Mission requirements

(c) Cost.

The primary factors are the state of the art, mission requirements, and cost - with the state of the art normally assumed to be composed of the basic areas of aerodynamics, propulsion, structures, and operations. It should not be assumed that the limit of what can be accomplished within the state of the art will automatically evolve from the level of knowledge in these four basic areas. Design ingenuity is shown, therefore, as a contributing item, since it plays a very important role in establishing what can be done.

The manner in which new aircraft designs come about does not always proceed according to the same pattern. Often, a mission requirement is first defined. If this is determined to be within the state of the art, the project may proceed rapidly, assuming, of course, that the cost is not excessive. Sometimes, an advance in the state of the art is necessary before the mission requirements can be met, and, at other times, the exercise of unusual design ingenuity will point the way to a means for meeting the mission requirements with no advances in any of the four basic areas under the state of the art. There have been many instances in which mission capabilities have been highlighted as a result of a breakthrough in one of the items under the state of the art. In such instances, a requirement may not appear until the full significance of the breakthrough is appreciated. This has, at times, been the situation following a variable-geometry innovation.

Figure 1 illustrates improvements that have been achieved as a result of the application of three variable-geometry features. Listed at the left are the capabilities of take-off and landing, range, maximum speed, rate of climb, rough-air response, and sonic-boom alleviation. The solid bars give a qualitative rating in the scale from poor to good that would exist if a particular variable-geometry feature were not included in the design. The extensions to the bars indicate the improvements that result from incorporating the variable-geometry features.

The first section of Figure 1 illustrates the gains realized from adding variable-pitch propellers to an airplane design typical of the 1940 time period. The increased thrust available at low forward speeds permitted a substantial improvement in take-off characteristics and in the rate of climb. The landing run was shortened as a result of the ability to reverse the thrust. Range and maximum speed were improved by being able to operate at maximum propeller efficiency and, to some extent, by being able to select a wing area more nearly compatible with cruise requirements, since compromises to satisfy other flight conditions were not as severe.

The second part of Figure 1 illustrates the result of applying high-lift flaps to an airplane design of the 1950's. Again, although the most significant improvement was achieved in the take-off and landing category, gains did result in all items, including rough-air response as a result of the ability to use a higher wing loading.

The third part of Figure 1 shows the improvements expected to result from incorporating variable wing sweep in an aircraft design appropriate to the 1960 time period. It is assumed that supersonic capability is required. In this case, very substantial gains are to be expected in take-off and landing performance and in range, if accomplished subsonically, because of the ability to convert the aircraft to an efficient subsonic configuration. Rate of climb also is improved, and some alleviation of the sonic boom results from the ability to accelerate to supersonic speeds at a higher altitude. A substantial improvement in rough-air response results from the ability to use a higher sweep angle and smaller wing area than could possibly be tolerated in a fixed-geometry configuration. Some slight gain in maximum speed also can be expected, since it is perhaps possible to provide a more nearly optimum high-speed configuration.

Figure 1 is intended to bring out the point that the introduction of a variable-geometry feature frequently makes it possible for an airplane to operate in a more nearly optimum configuration over a greatly increased range of operating conditions. Improvements, therefore, may be reflected in nearly all of the operating characteristics. Balanced against these improvements is the possibility of associated increases in weight, complexity and cost that may cause the variable-geometry feature to be unacceptable. These possibilities in the past were the basis for strong counter-arguments, particularly with respect to the introduction of slotted lift flaps, variable-pitch propellers, and retractable landing gear. They will continue to provide valid arguments with respect to future proposals for variable-geometry features, and whether they outweigh the claimed advantages of the item will depend largely on the ingenuity of the designer in providing an efficient system.

The aerodynamic factors that have led to the recent interest in varying the sweep angle of aircraft wings will now be considered briefly. The maximum lift-drag ratio is shown in Figure 2 as a function of Mach number for three airplane configurations. The first configuration can be regarded as a near-optimum subsonic design, which

provides a lift-drag ratio somewhat above 20 for subcritical Mach numbers, but cannot be considered as a supersonic or even transonic design. The next configuration might be regarded as optimum in the Mach range from 2 to about 3, but is very unattractive at subsonic speeds. Also shown is a configuration that is referred to as a fixed-geometry compromise. This can be regarded as a practical airplane designed for operation in the Mach 2 to 3 range, but without benefit of any unusual variable-geometry feature. Note that only a relatively small improvement is obtained at subsonic speeds with the fixed-geometry compromise when it is desired to approach closely the optimum supersonic performance.

The very wide difference in subsonic lift value that is achievable for the optimum subsonic and the optimum supersonic designs is illustrated in Figure 3. Again, the fixed-geometry compromise falls far short of providing the values of lift coefficient given by the subsonic configuration over the range of angles of attack that can be used in landing and take-off.

Figure 4 compares gust response in gravity units for the three configurations. This item is of considerable importance for high-speed aircraft in that it has a strong bearing on passenger comfort, pilot fatigue, structural loading, and accuracy of weapon delivery. The results shown apply to the response of an airplane with a wing loading of 60 lb/ft^2 to a simple sharp-edged gust of 50 ft/sec vertical velocity at sea level. The low-aspect-ratio airplane designed for optimum supersonic-cruise performance is characterized by a considerably milder response than the subsonic configuration, and the fixed-geometry compromise is only slightly inferior to the optimum supersonic design. It is of interest to consider, with respect to gust response, that an airplane having a variable-geometry wing can, conceivably, experience gust response that is even lower than that of the airplane designed for optimum supersonic-cruise performance, since the wing area can possibly be reduced below that desired for cruise.

The results given in Figures 12, 13 and 14 make it possible to define roughly the primary design requirements associated with a broad operational range (or multi-mission) capability. This is illustrated in Figure 5. The key design feature for the capabilities of long duration, long range, and short-field operation in take-off and landing is the long-span, unswept wing that is typical of our older subsonic airplanes. Efficient supersonic cruise requires a high wing-sweep angle, but there are definite acceptable lower limits to the wing area and the aspect ratio. The capability of operating satisfactorily during low-level penetration requires that the wing area be very small in order to minimize gust response and to reduce drag. If it is desired, therefore, to combine all five of these capabilities in a single airplane, a variable-geometry scheme must be devised to approximate the range of wing configurations.

Many of the thoughts that we have summarized occurred to several research workers shortly after the advantages of high sweep angles for supersonic flight first became evident. It was as a result of such considerations that a research program was started by the N.A.C.A. shortly after the Second World War. This program explored several schemes for varying the wing-sweep angle and eventually led to approval for construction of two variable-sweep airplanes as a part of the joint NACA/Air Force/Navy research airplane program. Photographs of one of these airplanes with its wing shown at minimum and maximum sweep angles are shown in Figure 6. The airplane was designated the X-5 and was built by the Bell Aircraft Corporation. The flight research program began in 1951 and was carried out over a period of several years.

The wind-tunnel and analytical program conducted prior to the X-5 revealed a basic stability problem, in that when the wings were rotated about a fixed pivot point located within the fuselage, the aerodynamic center moved considerably aft relative to the center of gravity, giving excessive stability as the wings were rotated rearward. The solution chosen for the X-5 involved mounting the wing on rails so that the wing root could be translated forward with respect to the fuselage as the sweep angle was increased. The more-forward position is evident in the photograph showing the wing at the maximum sweep angle. From an operational standpoint, this variable-sweep system was proven to be perfectly satisfactory in the flight program. The sweep angle was varied in flight over its entire range on many occasions, and no mechanical problems appeared. The variable-sweep feature undoubtedly did compromise the design of the X-5 to some degree, since the mechanism was quite heavy and the requirement for translation added to the bulk of the fuselage in the vicinity of the wing root. Consequently, the performance of the X-5 was not attractive for its time period; and, in addition, there were serious deficiencies in both the lateral-directional and the longitudinal stability characteristics. Nevertheless, the X-5 proved to be attractive in its short-field capabilities for landing and take-off and in its high rate of climb. These features and its good loiter characteristics made the X-5 very useful as a chase airplane in connection with the flight operations of other research aircraft.

Although the absence of attractive performance of the X-5 certainly did not add much encouragement for variable wing sweep in the 1953-55 time period, it is likely that other factors contributed to the fact that the concept was not more widely adapted. At that time there was little hope for achieving sustained supersonic cruise with any configuration, and, with the requirement limited to supersonic dash, a fixed configuration that was less than optimum supersonically, and still acceptable subsonically, seemed to be an acceptable compromise to the military services.

Advances in the state of the art with respect to both configurations and propulsion resulted in some change in the climate for variable-wing geometry during the years from 1956 to 1958. It became apparent that extended supersonic cruise could be achieved, but that the operations seemed to be limited essentially to a single design mission. Hope for greater mission breadth was revived, however, as a result of additional research conducted in this time period on variable-sweep concepts by both the British and the N.A.C.A. This work resulted in defining variable-sweep systems that were compatible with the requirements for supersonic cruise. The results of the NACA research program appeared to provide a fundamental basis for practical variable-sweep arrangements that required no wing translation. It was shown that the lifting area of an airplane could be divided between fixed and movable portions in such a manner that movements of the aerodynamic center caused by sweep variation did not present a serious stability problem. Figure 7 provides an explanation of the concept. Two configurations are shown: one with the wing pivot located at the edge of the fuselage, and the second with the pivot located in a more outboard position. Plotted at the bottom of the Figure is the distribution of wing aerodynamic loading along the length of the airplane. For the inboard pivot, it is obvious that the aerodynamic center - as represented by the vectors - moves rearward as the sweep angle is increased. When the pivot is located at a selected outboard position, however, the aerodynamic center for the swept configuration may be at the same location as that for the unswept configuration, or even slightly forward. This results from the fact that the lift on the movable panel decreases as the sweep angle is increased, but, to maintain constant lift on the entire

airplane, the angle of attack must be increased - thereby increasing the proportion of the total load carried on the forward fixed portion. By careful design, a pivot location can be determined which will result in a balance in the moments due to loads on the fixed and movable wing portions, thus providing essentially the same stability for both minimum and maximum sweep. It should be pointed out that if a design is selected in which the fixed portion is displaced considerably forward of the movable portion, as with a canard configuration, the pivot point can probably be located somewhat inboard of the location otherwise required.

Airplanes with variable-sweep wings must, of course, still contend with the problem of a rearward movement of the center of pressure associated with the change in load distribution in going from subsonic to supersonic speeds, as shown in Figure 8. It is assumed that the wing sweep is programmed from the minimum angle to the maximum angle in the transonic Mach number range, as indicated at the top of the Figure. At the bottom of the Figure, the aerodynamic center is expressed as a percentage of the wing chord for the maximum-sweep condition. Note that for the outboard pivot location the change in aerodynamic center in going from subsonic to low supersonic speeds is about 20 per cent of the wing chord, or roughly the same as would be expected of a fixed-geometry configuration over this Mach number range. In approaching Mach 3, the aerodynamic center moves forward, as is expected, because of the decreased effectiveness of the wing in producing moments about the center of gravity, in comparison to that of the fuselage. At a cruise speed in the neighborhood of Mach 2 to 3, a stability level low enough to avoid excessive trim drag can therefore be achieved with the outboard pivot location. On the other hand, the stability level at supersonic speeds for the inboard pivot configuration is very high on a rigid airplane and would result in excessive performance penalties as well as problems of controllability and loads. Some alleviation of the high stability level may, in some cases, result from aeroelastic effects.

The NASA (formerly NACA) variable-sweep research program developed rapidly after a practical method for overcoming the stability problem appeared to be in hand. Figure 9 gives an indication of the technical areas included. Note that the work on configurations became intensive in late 1958 and is still active, with the effort now directed toward various design refinements as well as to new applications. The extensive configuration studies performed have indicated that practical configurations can be designed that approach closely the ideal performance potential of the variable-sweep concept. Mission analyses were started early in 1959 and engine-cycle analyses began early in 1960. Both are still continuing. Studies of sweep mechanisms (including structural optimization) were a high-priority item for about two years and are continuing now on a reduced level of effort. Research on wing flutter, piloting and general operations began in late 1959 and is continuing.

Since the design of the wing pivot arrangement was recognized from the beginning as a potential problem, extensive analytical and experimental studies of various pivot designs have been made both by NASA and the aircraft industry. Three basic arrangements that were included in the studies are shown in Figure 10. These are: first, the track type; second, a type in which a large-diameter bearing is used; and, finally, a type employing a clevis and pin, which is illustrated for an inboard pivot location, although an outboard pivot can probably also be used. Each of these arrangements was tested extensively, and it is probable that any one could be applied successfully. In the NASA tests of the track-type pivot, a large model was constructed to represent the

pivot region, including portions of the wing structure inboard and outboard of the pivot. Static loads were applied to determine stiffness and stress-influence coefficients at various locations on the wing. Vibration surveys were made to determine natural frequencies and mode shapes. The experimental data were compared with calculated results. Structural-damping measurements also were made. Skin strains were measured at 49 stations and shear strains at 21 locations. Vertical deflections were measured by strain gages and horizontal deflections by dial gages. The measurements were made under various simulated loading conditions while the sweep angle was varied repeatedly between 20° and 102°. The results have been applied to the development of stiffness criteria with respect to static loading and flutter conditions.

The possibility of wing flutter also was recognized as a potential problem area. Many wind-tunnel and theoretical studies have been completed, and the design parameters required for avoiding flutter are fairly well established. Some interesting results from one of the studies are shown in Figure 11. Models were prepared to represent the three sweep angles shown. The panels were dynamically and elastically scaled and simulated the elastic restraint at the pivot point. Tests were made at various fixed Mach numbers while the dynamic pressure was increased until flutter, as indicated by strain-gage outputs, was indicated. The flutter boundaries determined from the tests are shown in relation to curves representing various altitudes. Flutter was encountered at dynamic pressures above the boundaries shown for the various sweep angles. The absolute levels of the flutter boundaries are, of course, a function of the actual structural characteristics. The relative effect of wing sweep shown is typical, however, of most designs, and it will be noted that the effect of sweep angle on flutter tends to be compatible with performance requirements, in that the higher sweep angles are flutter-free to higher dynamic pressures. It appears, therefore, that flutter can be avoided in actual missions by suitable programming of the wing sweep with Mach number and altitude.

In this Report we have touched only briefly on the variable-sweep program that has been carried out by NASA over the past several years. It is believed that the program has been sufficiently extensive to demonstrate conclusively the potential for accomplishing a considerably greater mission breadth by use of variable sweep than is possible when fixed-geometry wings are used. In order that the basic studies might be applied more directly to specific military and commercial aircraft, some first-order attempts at airplane design studies were made. Two of these designs are illustrated in Figure 12. At the left is a possible layout to meet a multi-mission requirement of a military aircraft. The wings are shown at the three sweep angles recommended for subsonic operation, supersonic cruise and low-level penetration. This configuration was studied extensively by both NASA and industry and contributed significantly to the development of the TFX (F-111) concept. The layout shown at the right represents a somewhat different approach in which the wing, when folded back, forms the leading edge of essentially an arrow-wing configuration. This second layout is of a type that might be considered for a commercial supersonic transport. Other design approaches are under study; however, the two shown illustrate many of the significant design features.

A somewhat broader perspective of variable-geometry applications can be obtained by considering the short history of the space program. Figure 13 shows the system in use in the Mercury program in which a parachute is deployed in order to accomplish safely the final leg in the descent of the space capsule to the surface of the earth. The recovery system for the Gemini capsule consists of a Rogallo para-wing, and

represents a somewhat more sophisticated application of variable geometry, in that it gives a maneuverability capability as well as the ability to reduce the rate of sink essentially to zero at the time of contact with the ground.

In considering the nature of manned space or aerospace missions, it seems evident that there are many possible applications for additional variable-geometry developments in the future. Each of the various phases of a space mission seems to present unique requirements for the configuration of the vehicle. One possible approach to a space mission in which the more expensive components of the system are recoverable is illustrated in Figure 14. Basically, it is a three-stage system. The first-stage booster is a winged airplane having a dual-cycle engine, probably a turbo-ramjet. At prescribed velocity and altitude, the upper stages are launched and the launching airplane descends for a conventional landing on an airfield. The second-stage booster may not be recovered; however, the third stage, which achieves orbital velocity, is capable of a controlled re-entry and horizontal landing. To achieve desired maneuverability, the re-entry vehicle may be provided with variable geometry, in the form of either variable-sweep wings or folding wing-tip tails, as shown in the sketches at the bottom of the Figure. For the total system, therefore, there are three major variable-geometry items: the three-stage vehicle, the dual-cycle engine, and the re-entry vehicle.

CONCLUDING REMARKS

An attempt has been made to show that the introduction of variable-geometry schemes has contributed substantially to the advancement of aeronautics over the entire history of the airplane and that a similar trend is to be expected with respect to the space program. The NACA-NASA program on variable wing sweep has been outlined, and it is contended that variable sweep is a logical means for overcoming certain specific deficiencies of aircraft in the present time period. New problems appear with the introduction of any variable-geometry item; however, based on the experience accumulated over the years, the problems are likely to be overcome when the potential advantage of the item is sufficiently large.

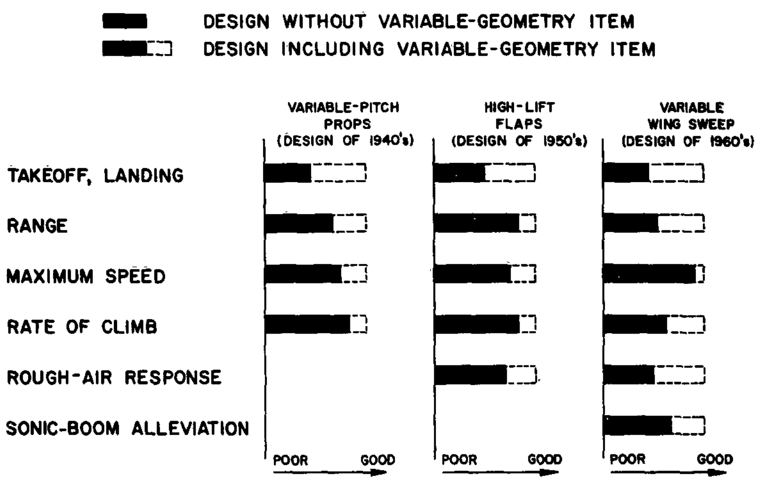

Fig.1 Gains due to variable geometry

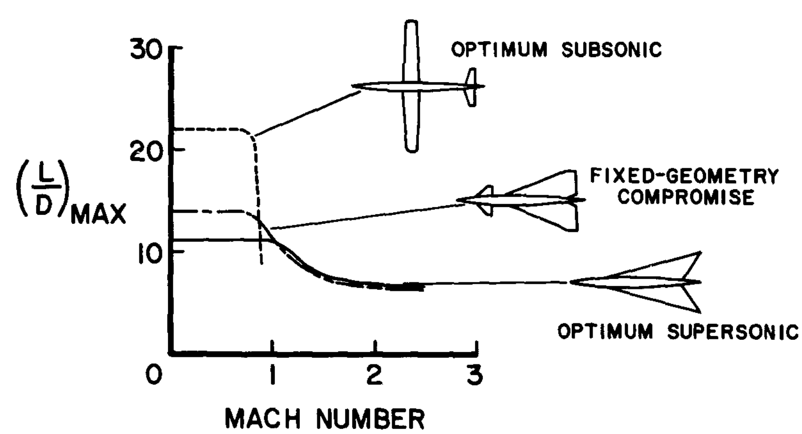

Fig.2 Performance characteristics

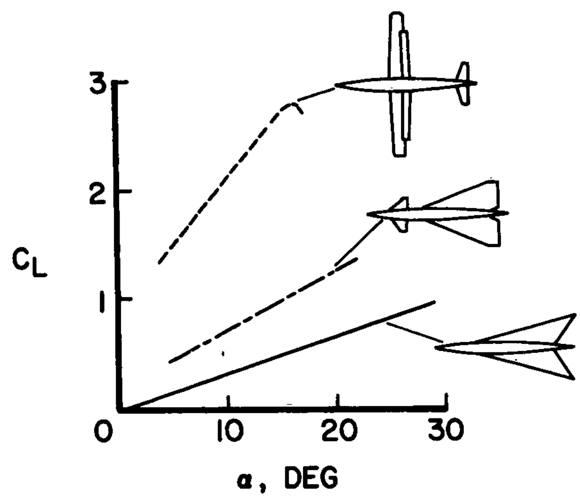

Fig.3 Subsonic lift characteristics

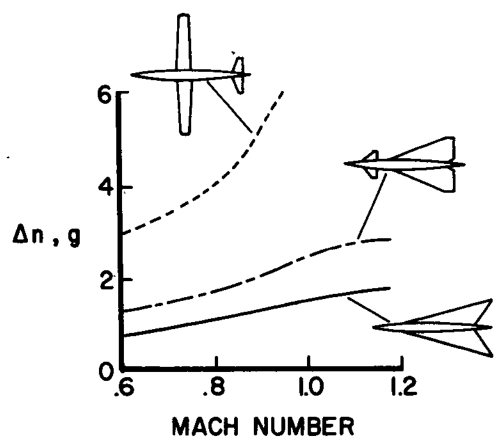

Fig.4 Low-altitude gust response. Sharp-edged gust, V_V = 50 ft/sec; sea level, $\frac{W}{S} = 60\ \text{lb/ft}^2$

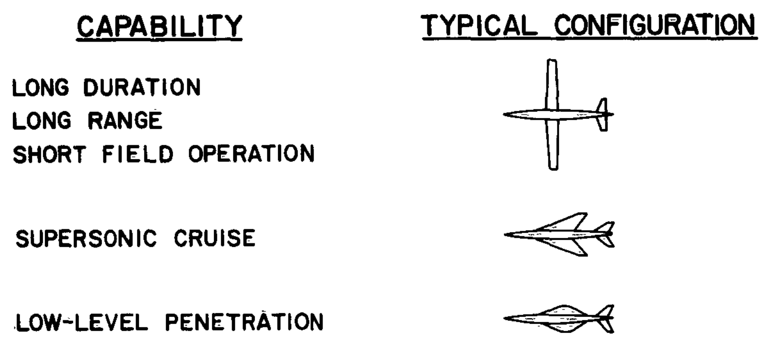

Fig.5 Multi-mission design requirements

MINIMUM SWEEP MAXIMUM SWEEP

Fig.6 X-5 research airplane

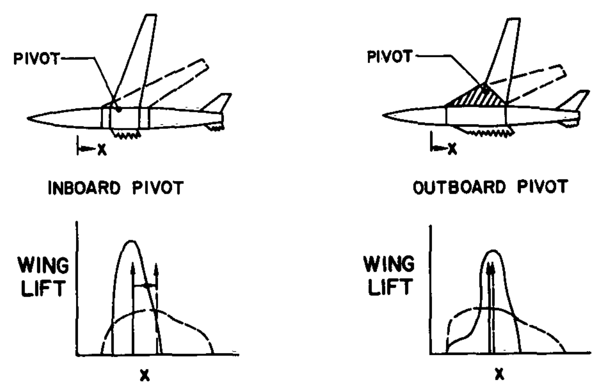

Fig.7 Effect of pivot location on aerodynamic loading

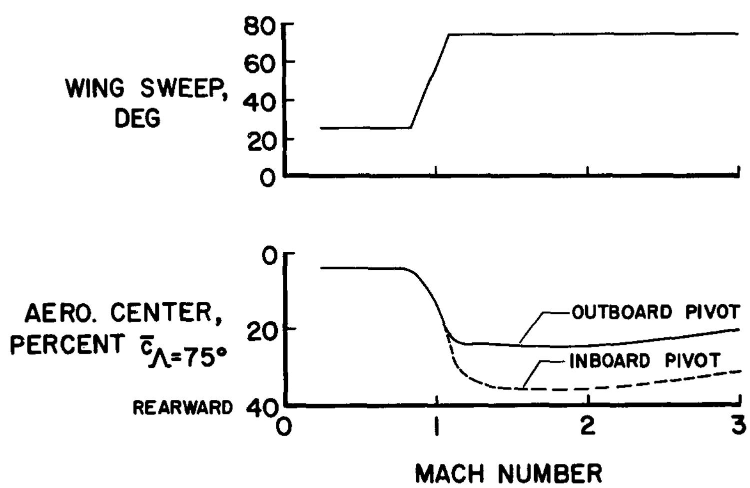

Fig.8 Aerodynamic-center characteristics

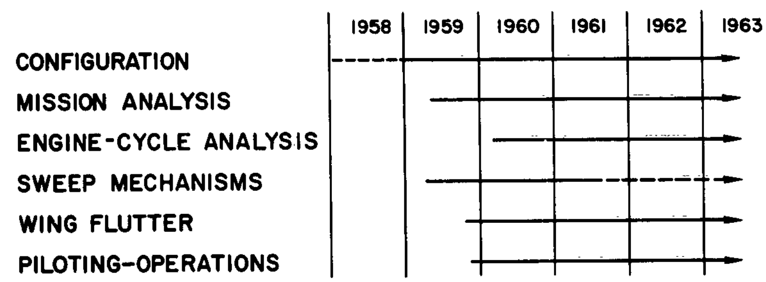

Fig.9 NASA variable-sweep program

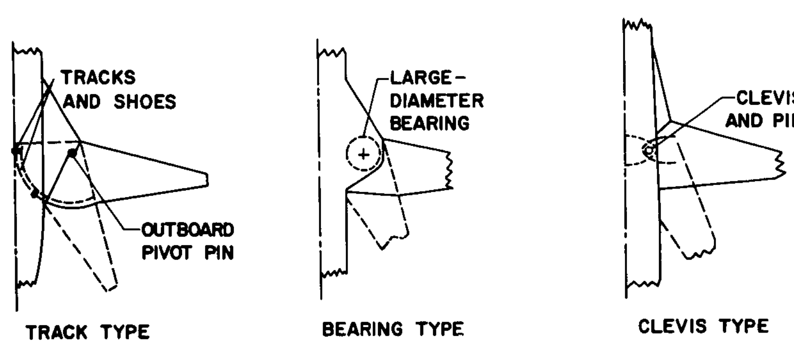

Fig.10 Pivot arrangements studied

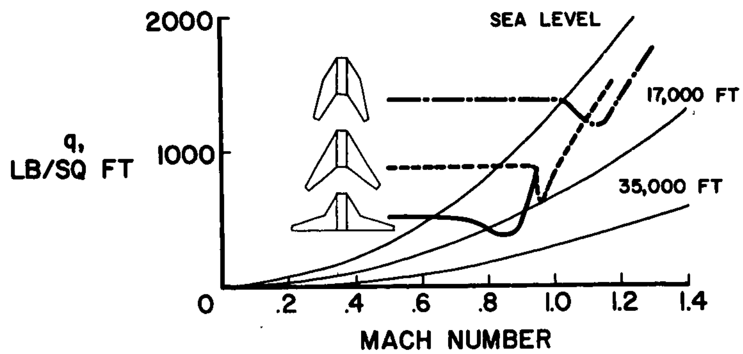

Fig.11 Typical flutter boundaries

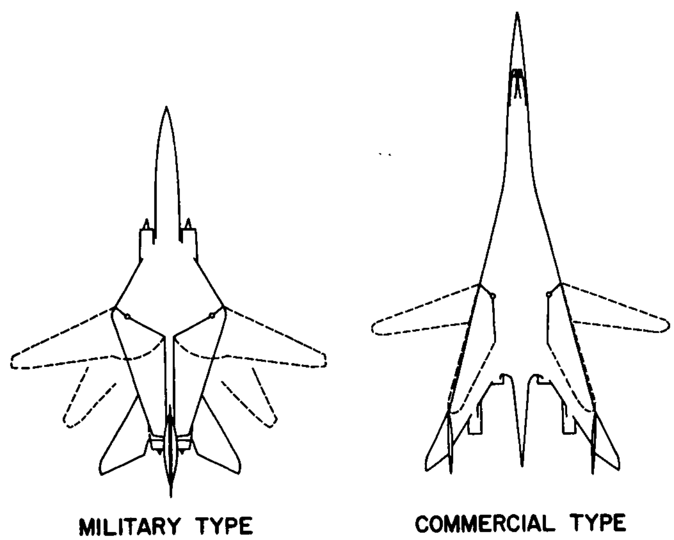

Fig.12 Variable-sweep applications

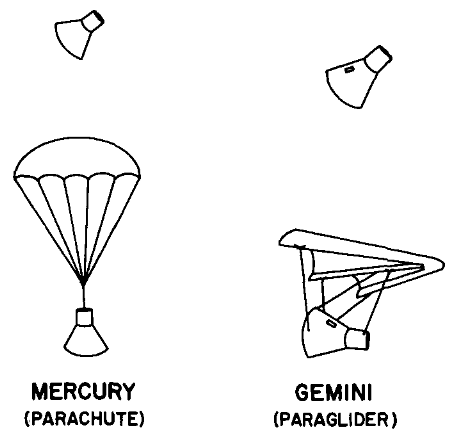

Fig. 13 Applications of variable geometry to space programs

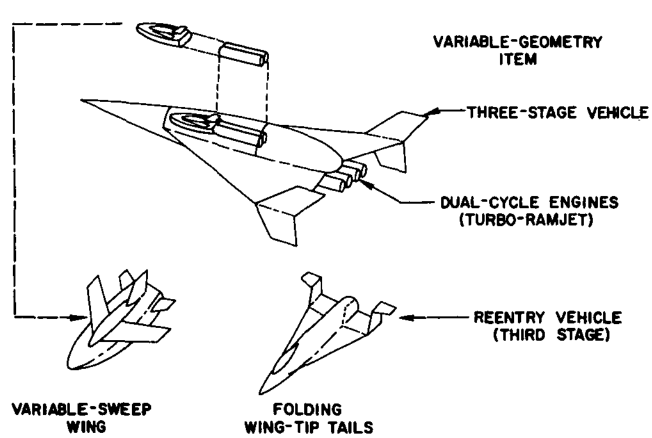

Fig. 14 Possible future applications of variable geometry

DISTRIBUTION

Copies of AGARD publications may be obtained in the various countries at the addresses given below.

On peut se procurer des exemplaires des publications de l'AGARD aux adresses suivantes.

BELGIUM BELGIQUE	Centre National d'Etudes et de Recherches Aéronautiques 11, rue d'Egmont, Bruxelles
CANADA	Director of Scientific Information Service Defense Research Board Department of National Defense 'A' Building, Ottawa, Ontario
DENMARK DANEMARK	Military Research Board Defense Staff Kastellet, Copenhagen Ø
FRANCE	O.N.E.R.A. (Direction) 25, Avenue de la Division Leclerc Châtillon-sous-Bagneux (Seine)
GERMANY ALLEMAGNE	Wissenschaftliche Gesellschaft für Luftfahrt Zentralstelle der Luftfahrtdokumentation Munchen 64, Flughafen Attn: Dr. H.J. Rautenberg
GREECE GRECE	Greek National Defense General Staff B. MEO Athens
ICELAND ISLANDE	Director of Aviation c/o Flugrad Reykjavik
ITALY ITALIE	Ufficio del Generale Ispettore del Genio Aeronautico Ministero Difesa Aeronautica Roma
LUXEMBURG LUXEMBOURG	Obtainable through Belgium
NETHERLANDS PAYS BAS	Netherlands Delegation to AGARD Michiel de Ruyterweg 10 Delft

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

AGARD Report 447
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
NASA VARIABLE-GEOMETRY RESEARCH
T.A. Toll, E.C. Polhamus and W.S. Aiken, Jr.
1963
15 pages, incl. 14 figs.

629.135:533.693.49
3c5

The past, present, and probable future research activities of NASA with respect to applications of variable geometry are outlined. A general discussion is given of the reasons for considering variable geometry. Past developments are summarized to show how they have resulted in increased operational flexibility of aircraft. Emphasis is placed on the variable-sweep program. The historical aspects and objectives of this activity are

P.T.O.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy 16-19 April 1963.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.

described briefly. The various approaches that have been investigated, along with some of their advantages, are described. The scope of the NASA program with respect to configurations, mission studies, structures, mechanisms, flutter, and piloting problems is outlined. The Report concludes with a brief expression of thoughts on possible future applications of variable geometry to both aeronautics and space programs.

Presented at the Twenty-Second Meeting of the Flight Mechanics Panel, held in Torino, Italy, 16-19 April 1963.